Concentrations of foliar and surface soil in nutrients *Pinus* spp. plantations in relation to species and stand age in Zhanggutai sandy land, northeast China

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Abstract: The concentrations of the foliar and surface soil nutrients and the variation with species and stand age were studied in *Pinus spp.* plantations in Zhanggutai area, northeast China. The results showed that the total N, total P and C: N ratio of the soil in *P. sylvestris* var. *mongolica* stands were significantly higher in comparison with those in *P. tabulaeformis* and *P. densiflora* stands. For *P. sylvestris* var. *mongolica*, the foliar P concentration appeared to decrease with age, and the foliar N and K concentrations did not show a consistent change with age. As for the different tree species of the similar age, the foliar N and P concentrations were significantly different ($p<0.05$), being with *P. sylvestris* var. *mongolica* > *P. densiflora* > *P. tabulaeformis*. The foliar N: P ratio of *P. densiflora* significantly was higher than *P. sylvestris* var. *mongolica* and *P. tabulaeformis*, while the foliar K was no obvious difference between the three tree species. There were significant correlation ($p<0.05$) between soil total N and P, soil organic matter and total P, foliar N and P, but it did not show significant correlations between soil and foliar nutrient concentrations, which might attribute to the excessive litter raking, overgrazing and low soil moisture in this area. Based on the foliar N: P ratio, we introduced a combination threshold index of N: P ratio with their absolute foliar nutrient concentrations to determine the possible limiting nutrient. According to the critical N: P ratio and their absolute foliar N, P concentrations, the *P. sylvestris* var. *mongolica* stands showed a decreased N limitation degree with age, the *P. densiflora* stands showed unlimited by N and P in the whole, and the *P. tabulaeformis* stands showed co-limited by N and P. No significant difference in soil nutrient concentrations of the surface soils was found between 45, 29, 20-yr-old *Pinus sylvestris* var. *mongolica* plantation stands.

Keywords: coniferous trees; foliar nutrient concentration; limiting nutrients; N: P ratio; Zhanggutai sandy land

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Introduction

Foliar nutrient concentrations have been widely recognized as an effective measure of the nutritional status of plants (van den Driessche 1984; Chapin 1980; Bouma 1983; Tamm 1995). Leaves were the primary sites of physiological activities of plants (Moorby & Besford 1983), foliar nutrient concentrations of plants could convey various information of plant eco-physiology, including leaf photosynthetic and dark respiration rates (Field and Mooney 1986; Reich *et al.* 1992), gas exchange and nutrient storage (Moorby and Besford 1983), soil and air pollution (Klumpp *et al.* 2002; Nieminen & Helmisaari 1996), growth capacity (Cornelissen *et al.* 1997; Thompson *et al.* 1997), nutrient resorption efficiency and proficiency (Killingbeck 1996), nutrient uptake (Ryan and Bormann 1982), and adaptations of trees to nutrient stress (Boerner 1985). In addition, foliar nutrient concentrations influenced ecosystem processes, such as leaf litter decomposition, nutrient mineralization, and so on (Melillo *et al.* 1982; Enriquez *et al.* 1993; Enoki and Kawaguchi 2000).

Variation in foliar nutrient concentrations might arise from the variation of soil nutrient availability, or age differences of trees, or inherent physiological differences among species and growth forms. Some research results showed that the concentrations of foliar nitrogen (N), phosphorus (P), and base cations could reflect their relative availability across different sites (Vitousek *et al.* 1992; Foulds 1993; Crews *et al.* 1995; Thompson *et al.* 1997). However, foliar nutrient concentrations also varied widely among individual plant of different species and growth form within sites. Leaves of evergreen species (and species with slow leaf turnover) tend to have lower N and P concentrations than those of deciduous shrubs, trees, and herbaceous species (species with faster leaf turnover) (Field and Mooney 1986; Reich *et al.* 1992; Aerts and Chapin 2000). Variation among growth forms appeared to reflect the differences of inherent growth form in the capacity for rapid growth, with fast-growing species having higher concentrations than slow-growing species (Cornelissen *et al.* 1996). Finally, variation of concentrations of some nutrients in leaf might arise from their close association with other nutrients. For example, N and P tend to be tightly correlated among species, presumably because of their similar physiological roles as components

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of nucleic acids, membranes, and so on (Garten 1976).

There are now about 3 000 hm^2 woodlands in Zhanggutai area, southeastern Ke'erqin sandy land, primarily including *Pinus sylvestris* var. *mongolica*, *P. tabulaeformis* and *P. densiflora*tree species, and among which the *P. sylvestris* var. *mongolica* woodlands accounted for about half of that (Wu *et al.* 2002). As the population of Zhanggutai area has soared in these years, the human disturbances to the forest stands have also increased, including excessive litter raking, underground water using and overgrazing. The activities of litter raking in this area have greatly influenced the forest ecosystems, from our investigation, about 90% of the grass and foliar litters have been collected away by the local people, which brought about large quantities nutrients away from the forest ecosystem every year. Considering these human disturbances, the foliar nutrients became more and more important for the nutrients preservation of stand in the forest ecosystems. Since the1990s, there has been a large area of *P. sylvestris* var. *mongolica* trees died of certain causes, as for the factors of the decline, there have been many assumptions introduced to explain, but till now no specific theories could successfully interpret it. We hypothesized that the decline of *P. sylvestris* var. *mongolica* trees might be partly due to low soil nutrient content and soil water deficiency in this area. In this paper, we explored the foliar nutrient concentrations of different age-gradient *P. sylvestris* var. *mongolica* and different coniferous species in this area, as well as the surface soil nutrient of these forest ecosystems.

The objectives of this study are: (1) to compare leaf nutrient concentrations of *P. sylvestris* var. *mongolica* among 3 age gradients, and of the different coniferous species of the similar age; (2) to determine whether foliar nutrient concentrations reflect underlying variation in soil nutrient concentrations or, instead, are relatively invariant within or between species, regardless of variation in site nutrient availability; (3) to explore whether N, P, or N and P, is the possible limiting nutrient element to the growth of pine trees in this area.

Materials and methods

Study sites

The experiments were conducted at Experimental Forestry Center, the Institute of Sand-fixation Afforestation, Zhanggutai, Liaoning Province, eastern Ke'erqin sandy land, China. The experimental area belongs to arid-sub-humid region, the mean annual temperature is 5.7°C, and the extreme lowest and highest temperatures are -29.5°C and 37.2°C, respectively. Mean annual precipitation is 450 mm, the extreme lowest and highest annual precipitations are separately 224.8 mm and 661.3 mm. Annual evaporation is about 1 700 mm, and free frost period is about 154 d (Wu *et al.* 2002). The average altitude of this area is 226.5 m. Major soil types are aeolian sandy soil and meadow soil, the relative atmosphere humidity is 58%, and average groundwater table is 5.3 m. The dominant plant species include: herbages such as *Artemisia capillaries* var. *simple*, *A. frigida*, *A. sacrorum*, *Pennisetum flaccidum*, *Cleistogenes chinensis*, *Hedysarun fruticosum*, *Salix microstachya* var. *bordensis*, *Poentilla chinesis*, and so on; shrubs such as *Caragana microphylla*, *Prunus sibirica*, *Lespedeza davurica*, and so on; and tree species such as *P. sylvestris* var. *mongolica*, *Ulmus pumila*, *P. tabulaeformis*, *P. densiflora*, and so on.

In order to investigate the effects of tree age on foliar and soil nutrient concentrations in *P. sylvestris* var. *mongolica* stands, three age-stage of stands (20, 29 and 45 years old, respectively) were selected in this study. One experimental plot (20 m×20 m) was set up in each stand, and the same size plot was also separately set up in *P. tabulaeformis* stand and *P. densiflora* stand. The trees in the plots were evenly distributed. During the period of investigation, no pest and disease occurred. The characteristics of the five experimental stands were listed in Table 1.

Table 1. Some characteristics of the experimental stands measured in 2003

Stands	Symbol	Age /a	Number of trees /hm^2	Mean DBH /cm	Mean height /m
Pinus sylvestris var. *mongolica*	S20	20	1200	10.58	6.23
P. sylvestris var. *mongolica*	S29	29	825	13.65	7.53
P. sylvestris var. *mongolica*	S45	45	825	18.78	13.06
Pinus tabulaeformis	T31	31	775	16.40	8.54
Pinus densiflora	D29	29	950	13.30	7.86

Soil and leaf sampling

The diagonal method was used in the process of soil sampling. Soil samples were taken on October 29, 2002 from the experimental stands. Three soil cores were collected from the immediate surrounding of each experimental tree and mixed into one sample to be analyzed, and altogether 10 soil samples of each experimental plot were taken and analyzed. Only the lower soil layer at the depth of 0-15 cm was taken, because it was the primary layer that supplied the trees with nutrients and also the most active layer of nutrient transformation.

All trees within the 5 stands were measured for: number of trees, tree height, and diameter at breast height (DBH). The sample trees were selected on the basis of the average DBH and tree height, this selecting method was advantageous as it took into account "average trees".

Monthly leaf samples of every plot were collected on the 15 trees for 3 months during a quarter of biological cycle, from April to June, 2003 (spring). For each experimental

tree, we collected all the existing age-class leaves of 4 first-order branches (one branch of every direction), each class took 50 needles, then mixed them together to get an even sample, and thus minimized the foliar nutrient differences caused by leaf age. Altogether 15 samples of every plot (except for 29-year-old *P. sylvestris* var. *mongolica* plot, which were 31 samples for two current densities) were taken and analyzed. First-order branches were collected from the same height of the experimental trees, for nutrient concentration might vary with leaf position (Oliveira *et al.* 1996).

Laboratory analysis

The leaf samples were washed for one minute with demineralized water to remove any dust, oven-dried at 70°C for 48 h, and screened with a 0.25 mm sieve. Foliar K concentration was measured by flame ionization, and the samples were treated by sulphuric acid digestion (320°C) using a selenium mixture as catalyst, then total nitrogen concentration was determined with Kjeldahl procedure, and total phosphorus concentration was determined colorimetrically.

The chemical characteristics of soil were analyzed with the common methods. Soil total N and P concentrations were determined by the same methods with foliar N and P concentrations, organic matter was determined by the $K_2Cr_2O_7$-H_2SO_4 method, the soil total K was determined by NaOH melt flamer method, and the moisture of soil sample was determined by oven-drying the field-moist samples overnight at 105℃.

Statistical analysis

Analysis of variance (SPSS 10.0) was used to determine the differences among mean values in each stand and analyze the correlation between the nutrient elements. In cases where there was a significant difference at $P<0.05$, LSD (Least Significant Difference) test was used for multiple comparisons.

Results

Soil nutrients

The nutrient concentrations of soil were very low in these research plots (Table 2), and in view of the low soil organic matter (SOM) concentrations, which were all lower than 10 $g \cdot kg^{-1}$, the soils in this area were extremely poor, although trees established in this area for nearly 50 years.

For the *P. sylvestris* var. *mongolica* stands of three different ages, the concentrations of soil organic matter, total N, total P, and total K were similar (see Table 2). The pH value of 45-year-old *P. sylvestris* var. *mongolica* stand was significantly lower than those of the 29 and 20-year-old stands, which might show that, with the increase of age, the pH value decreased. The C: N ratio of 45-year-old stand was significantly higher than those of the 29 and 20-year-old stands.

As for the different coniferous tree species of the similar age, the concentrations of SOM, total K and available K were similar, while the concentrations of total N and total P of S29 (29-year-old *P. sylvestris* var. *mongolica* stand) were significantly higher than those of T31 (31-year-old *P. tabulaeformis* stand) and D29 (29-year-old *P. densiflora* stand). And the concentrations of soil total P and N were no significant differences between T31 and D29. The C: N ratio of S29 was significantly lower than those of T31 and D29, which indicated that the soil decomposition ability in the *P. sylvestris* var. *mongolica* stands exceeded those of *P. tabulaeformis* and *P. densiflora*. And the pH value of T31 was significantly lower than those of S29 and D29.

Table 2. Surface soil (0-15 cm) nutrient concentrations in five experimental stands (n=10)

Stands	Soil moisture $/g \cdot kg^{-1}$	Soil organic matter $/g \cdot kg^{-1}$	Total N $/g \cdot kg^{-1}$	Total P $/g \cdot kg^{-1}$	Total K $/g \cdot kg^{-1}$	Available K $/mg \cdot kg^{-1}$	pH value	C: N ratio	N: P ratio
S45	32.92ab	8.81a	0.362a	0.117a	17.27	51.16	6.09a	14.42ab	3.08
	(1.39)*	(0.39)	(0.035)	(0.005)	(0.69)	(4.15)	(0.05)	(0.79)	(0.20)
S29	37.35a	6.87	0.415a	0.111a	18.37	47.78	6.67b	11.60a	3.79a
	(2.42)	(0.44)	(0.020)	(0.005)	(0.53)	(1.18)	(0.05)	(0.80)	(0.22)
S20	31.61ab	6.81	0.420a	0.106a	19.20	47.23	6.71b	9.45c	3.96a
	(1.52)	(0.30)	(0.043)	(0.003)	(0.61)	(2.01)	(0.06)	(0.56)	(0.45)
T31	29.42b	7.05	0.260b	0.086b	17.82	42.64	5.94a	17.37b	3.10
	(1.44)	(0.88)	(0.028)	(0.006)	(0.92)	(4.41)	(0.13)	(2.68)	(0.45)
D29	28.68b	6.59b	0.219b	0.092b	18.6	44.21	6.62b	17.89b	2.40b
	(2.04)	(0.44)	(0.016)	(0.005)	(0.81)	(2.47)	(0.03)	(1.97)	(0.22)

*Mean value and the figures in the parentheses were 1SE (SE, standard error).

Foliar nutrient concentrations in *P. sylvestris* var. *mongolica* along three age gradients

Foliar nutrient concentration was widely recognized as an effective measure of the nutritional status of plants (Chapin 1980), and variation in foliar nutrient concentrations might also reflect the differences among species and growth forms (Vitousek *et al.* 1992). The N, P and K were the common limiting nutrient elements of many ecosystems, so here we set the three elements as research objects. As shown in the

Fig.1, foliar P concentration of *P. sylvestris* var. *mongolica* increased with age, as for foliar N, although the concentration of 20-year-old stand significantly higher than those of the 29 and 45-year-old stands, the change trend with age was not clear, this phenomenon might be explained that the disturbances of human being might be stronger in the 45-year-old *P. sylvestris* var. *mongolica* stand than those of the other two age-gradient stands, thus caused the soil nutrients could not be available for the trees in this stand. The foliar K concentrations differed very little between the three stands, but the N: P ratio decreased significantly with the increase of the age (respectively 12.52, 10.09, 9.03).

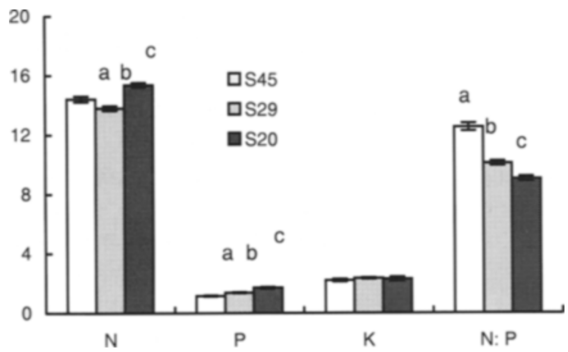

Fig.1 Variation in N, P and K concentration and the N: P ratio of *P. sylvestris* var. *mongolica* needles with stand

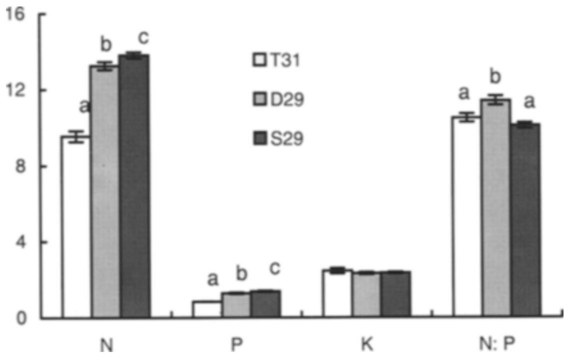

Fig. 2 Foliar nutrient concentrations and N: P ratio of the three coniferous species /mg · kg^{-1}

Foliar nutrient concentrations in different coniferous tree species

Variation in foliar nutrient concentrations might also reflect the differences between species and growth forms (Vitousek *et al.* 1992). As shown in Fig. 2, the foliar nutrient concentrations of N and P of different species of the similar age showed an obvious trend with an order of S29>D29>T31, and there was no significant differences of K concentration between these three coniferous species. The N: P ratio of *P. densiflora* (11.39) was significantly higher than those of *P. tabulaeformis* (10.48) and *P. sylvestris* var. *mongolica* (10.09), while there was no significant difference between *P. tabulaeformis* and *P. sylvestris* var. *mongolica*.

Discussion

Soil nutrients related to tree age and species

The nutrient concentrations of surface soils reflected the nutrient quantity of litters that returned to the soil ecosystem. Because of the excessive litter raking in Zhanggutai area, there was few litters left on the stand ground, the surface soil nutrient concentrations were still very low after trees introduced into this area (see Table 2). The pH value of 45-year-old *P. sylvestris* var. *mongolica* stand was significantly lower than those of 29 and 20-year-old stands, which might show that, with the age increasing, the pH value decreased. The lower pH value might due to the absorption of base cations, which was gradually increased by anchoring them into biomass of the trees. We could conclude that impacts of stand age on the surface soil nutrient concentrations were very limited, and this result might be interpreted by the excessive litter raking by the local people, which caused the litters could not return to the surface soil.

Compared with the soil nutrients of *P. tabulaeformis* stand and *P. densiflora* stand of the similar age, in the whole, the *P. sylvestris* var. *mongolica* had more beneficial effects on N and P nutrient concentrations of surface soils. The C: N ratio of 29-year-old *P. sylvestris* var. *mongolica* stand was significantly lower than those of 31-year-old *P. tabulaeformis* stand and 29-year-old *P. densiflora* stand, which might also imply that *P. sylvestris* var. *mongolica* had stronger influence on the soil biotic or abiotic environment than the other two species, and on the other hand, the lower C: N ratio of 29-year-old *P. sylvestris* var. *mongolica* further testified its higher N and P concentrations in the surface soil than those of the other coniferous species, for the higher C: N ratio was, the slower of the mineralization rate of organic N and P anchoring in litters into soil available N and P pool.

Correlation between soil and foliar nutrients

As showed in Table 3, except for between SOM and STP (Soil total P), STP and STN (Soil total N), there were no significant correlations between other soil nutrient elements. This correlation between SOM and STP ($p<0.01$) might be due to the characteristics of P sources. The primary sources of P were the weathering of rocks and withdrawal of plant tissues fell on the surface ground. Since the experimental area belonged to sandy area, and most rocks were fully weathered in the past decades, the supply of P from rock weathering with age was very limited, and thus the primary supplement source of P into the soil was the P withdrawal from the decomposition of plant litters. On the other hand, SOM directly reflected the nutrient supply quantity of plants to the surface soils. Therefore, the P concentrations corre-

lated significantly with SOM. This result might be confirmed by the relationship between STN and SOM. For the STN of surface soil, its supply sources primary included withdrawal from litters, N fixation by plants and N deposition from atmosphere, and N withdrawal from litters was not the only source of soil N, thus it did not show significant correlation with SOM.

Many researches had indicated that N and P tended to be tightly correlated among species, presumably because of their similar physiological roles as components of nucleic acids, membranes, etc. (Garten 1976; Aerts & Chapin 2000). Variation of concentrations of some nutrients in leaf might arise from their close association with other nutrients. For example, variation of foliar P concentration might simply reflect variation of N that arose from differences in foliar N availability and vice versa. As shown in Table 3 and Fig.3, foliar N concentration correlated significantly ($p<0.01$) with foliar P concentration, here we established the linear relationship between foliar N (Y) and P (X) as: $Y=5.4176X+0.6492$ ($R^2=0.61$, $p<0.05$).

Species had different nutrient requirements, and exploited nutrients with varying efficiency and stored or converted nutrients to biomass at different rates (Chapin 1980; Marschner 1986; Aerts & Chapin 2000). Nutrient availability had a key influence on plant growth. Grime *et al.* (1997) described mineral nutrients as "the fundamental currency of vegetation processes at scales from the individual to ecosystems and landscapes". However, there had also many opposite researches indicated that there was no clear relationship or negative relationship between soil nutrient availability and foliar nutrient concentrations (Lajtha and Whitford 1989; Chapin & Moilanen 1991; Del Arco *et al.* 1991). In this study, we did not find significant correlations between soil nutrients and foliar nutrient concentrations, which might due to the soil nutrient availability was very low induced by the human activities, such as excessive litter raking, underground water use and overgrazing, as well as low rainfall in this area. These disturbances lowered the soil nutrient availability, and broke the correlations between soil nutrients and their availability, as well disrupted the normal nutrient turnover between soil and plants, thus the correlations between soil total nutrients and foliar nutrient concentrations were also broken.

Table 3. Correlation between soil and foliar nutrient concentrations

	SOM	STN	STP	STK	pH value	Soil C: N	FN	FP	FK	Foliar N: P
SOM	1									
STN	0.34	1								
STP	0.51**	0.47*	1							
STK	0.15	0.13	-0.01	1						
pH	-0.02	0.25	0.05	0.24	1					
Soil C: N	0.18	-0.82**	-0.17	0.09	-0.22	1				
FN	-0.03	0.66	0.78	0.41	0.67	-0.70	1			
FP	-0.47	0.65	0.48	0.79	0.87	-0.76	0.78**	1		
FK	-0.79	-0.53	-0.53	0.54	0.56	0.37	0.09	0.21	1	
Foliar N: P	0.60	-0.44	0.20	-0.70	-0.37	0.52	-0.17	-0.74*	-0.23*	1

Note: STN: soil total N; STP: soil total P; STK: soil total K; FN, FP, FK: Foliar N, P, K, respectively

Limiting elements for the tree growth in this area

According to Liebig's Law of the Minimum, site fertility to individual plant was governed by the availability of the limiting nutrient. For individual plant, nutrient limitation was recognized by an increase in growth in response to an addition of the limiting nutrient into soil (Chapin *et al.* 1986). However, the fertilization experiments were time consuming, laborious and disturbing to the study site (Koerselman and Meuleman 1996). Thus, it would be beneficial to have a tool that gave the same information as a fertilization experiment, but faster, cheaper and with fewer disturbances. In the recent years, the N: P ratio of the plant tissues was introduced as a method to detect the limiting elements for the growth of plants (McKee 1993; Koerselman & Meuleman 1996; Willby *et al.* 2001; Aerts & Chapin 2000; Güsewell & Koerselman 2002; Tessier & Raynal 2003; Aerts *et al.* 2003).

According to the thresholds of N: P ratio in leaves, the nutrient conditions were categorized: (1) P-limited, (2) N-limited; (3) co-limited by N and P; (4) no limitation. Based on a large number of different vegetation types and plant species in different wet ecosystems in Europe, thresholds of foliar N: P ratios were found that N: P ratio < 14 and tissue [N] < 20.0 $g \cdot kg^{-1}$ was regarded as indicator of N limitation, and N: P ratio > 16 and tissue [P] < 1.0 $g \cdot kg^{-1}$ was regarded as an indicator of P limitation, and in the range of N: P ratios 14-16, tissue [P] < 1.0 $g \cdot kg^{-1}$and [N] < 20.0 $g \cdot kg^{-1}$ was considered co-limited by both nutrients (N-P co-limitation) in this area (Wassen *et al.* 1995; Koerselman & Meuleman 1996; Aerts & Chapin 2000). However, there was also another threshold of N: P ratio established by Braakhekke and Hooftman (1999). They established a critical N: P ratio of 10 and 14, respectively, as the N-limitation and P-limitation through researching on the plants of mesotrophic and nutrient-poor grasslands. Considering the similar habitats with what reported by Braakhekke and Hooftman, here we introduced the critical N: P ratio of 10, 14 and their absolute nutrient concentrations as an index to determine the possible limiting nutrients of N and P in the research area. As

showed in Fig.3, we divided the trees into three zones according to N or P limitation.

As for the forest ecosystems of *P. sylvestris* var. *mongolica* along an age gradient, N limitation degree showed a decreasing trend with the increase of age. All the foliar N: P ratios of S45 (average 12.52) exceeded 10 and their foliar P concentrations were also higher than 1.0 mg·kg^{-1}, which indicated that the trees of S45 were unlimited by N or P; about half of the foliar P concentrations of S29 were less than 1.0 mg·kg^{-1}, so the distribution zones of S29 spanned two zone (unlimited and limited by N); and although the foliar P concentrations of the S20 were higher than 1.0 mg·kg^{-1}, the N: P ratios of S20 were lower than 10, so the S20 showed a trend limited by N. These results might be explained by that P availability in soils essentially declined through the course of soil development, while N availability increased with humus accumulation, N fixation and N deposition, and this also implied that the N fixation and atmosphere deposition might be very important for the N availability of the trees in this research area.

As for the forest ecosystems of different coniferous species of the similar age, the *P. densiflora* (average N: P ratio=11.39) and *P. sylvestris* var. *mongolica* (10.09) all spanned zones II (unlimited) and III (limited by N), but they unlimited by N and P in the whole. Because all the foliar P concentrations of *P. tabulaeformis* (average N: P ratio=10.48) were lower than 1.0 mg·kg^{-1} and their foliar N concentrations were also lower than 20 mg·kg^{-1}, the ecosystem showed N limitation.

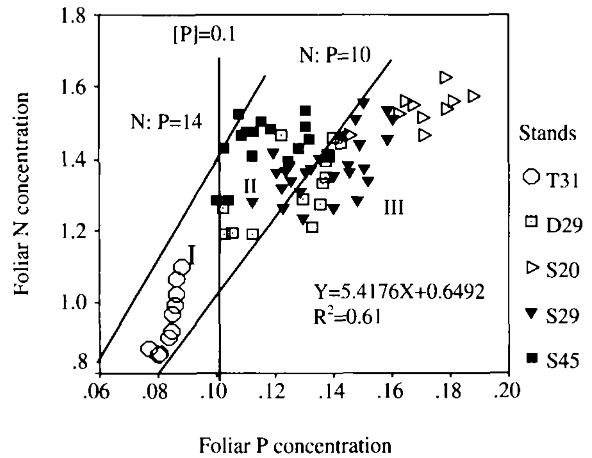

Fig.3 Correlation between foliar N and P concentrations /%

Note: I: Co-limited by N and P; II: Unlimited; III: limited by N

Although critical nutrient contents and their ratios had received broad endorsement in subsequent fertilization studies, it was an imperfect tool that provided only circumstantial and specific species evidence of nutrient limitation (Boeye *et al.* 1997; Wassen *et al* 1998; Van Duren & Pegtel 2000). The combined thresholds of N: P ratio and absolute nutrient concentration thresholds were introduced and validated by researches for the grassland and wetland ecosystems in Europe and North America, therefore, the thresholds might be inaccurate to be used in the arid and semi-arid sandy area, especially in China. Thus, we need carry on fertilization experiments to validate the critical N: P ratio that could accurately evaluate the limiting nutrients in eastern Keerqin sandy land.

At present, many researchers in China still used fertilization experiments to determine whether the ecosystems or vegetation were limited by nutrients and which nutrient elements limited them. There was no reports about using the N: P ratio of plant tissue and their absolute nutrient concentrations to evaluate limiting nutrient elements for the growth of plants in China, so here we introduced this index, with aim to establish nutrient limiting thresholds in this area in the near future.

Ability of trees adapting to poor habitats

Adaptation to variation of nutrient availability in soils leaded to plant nutrient concentrations differed widely between organs, species and ecosystems. Many researches had shown that concentrations of leaf nutrients can be regarded as traits that responded plastically to environmental variability and had tested whether a consistent pattern of nutrient covariation among populations could be expected as a result of the plant's acclimation to a given environment (Alonso & Herrera 2001; Pugnaire 2001), and stress-tolerator dominated stands had consistently lower nutrient contents and higher N: P ratios (Willby *et al.* 2001). From these research results, combined with the foliar N and P concentrations of *P. sylvestris* var. *mongolica* (Fig.1), we could deduce that this tree species showed an increasing adaptive ability to the research area with the increase of age, which might mean that the tree species had altered the surroundings to adapt to its growth. From this result, we could conclude that the degradation phenomenon of *P. sylvestris* var. *mongolica* was not induced by increased age, which might arise from other causes, such as plant diseases and insect pests, soil water deficiency, high tree density, inclemency to local climate and long-term drought stress. And according to the foliar nutrient concentrations (Fig.2) of different stands, we could not judge which tree species was more suitable for the low soil nutrients and nutrient availability of the research area.

Cornellisen *et al.* (1996) and Reich *et al.* (1992) had suggested that variation among growth forms appeared to reflect inherent growth differences in the capacity for rapid growth, with fast-growing species having higher foliar nutrient concentrations than slow-growing species. So through our study result that the foliar N and P concentrations of *P. densiflora* and *P. tabulaeformis* were lower than those of *P. sylvestris* var. *mongolica* of the similar age (Fig. 2), we could also deduce that the growth rate and productivity of *P. sylvestris* var. *Mongolia* trees were higher than those of *P. densiflora* and *P. tabulaeformis*, and this result was consistent with the real condition (Dry biomass for the three tree species: 51.93 kg per average tree for 29-year-old *P. syl-*

vestris var. *mogonica*, 51.64 kg for 29-year-old *P. densiflora*, 40.29 kg for 31-year-old *P. tabulaeformis*).

The higher the growth rate and foliar nutrient concentrations of trees, the higher the nutrient content anchoring in the trees, so considering the low soil nutrient content, low rainfall, sandy soil characteristics and strong human disturbances (litter raking and overgrazing) in the research area, although we could not judge which tree species was more adaptive to the low soil nutrients and nutrient availability of the research area, we could deduce that the tree species *P. sylvestris* var. *mongolica* might not suitable for the research area in view of its higher foliar nutrient content than *P. tabulaeformis* and *P. densiflora*.

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